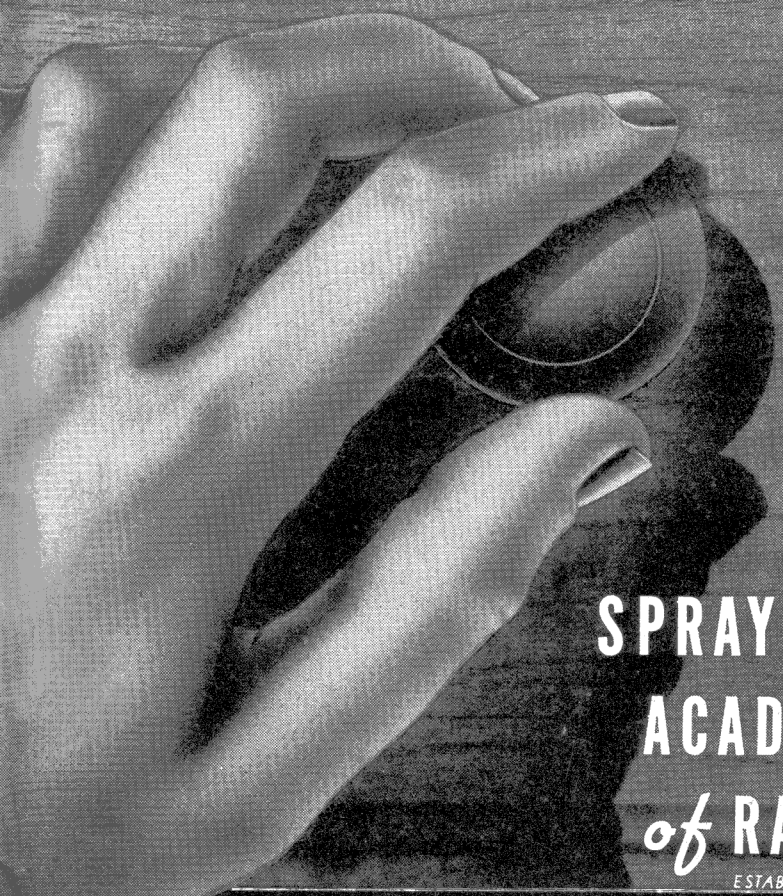
How Sound Is Employed In the Movies

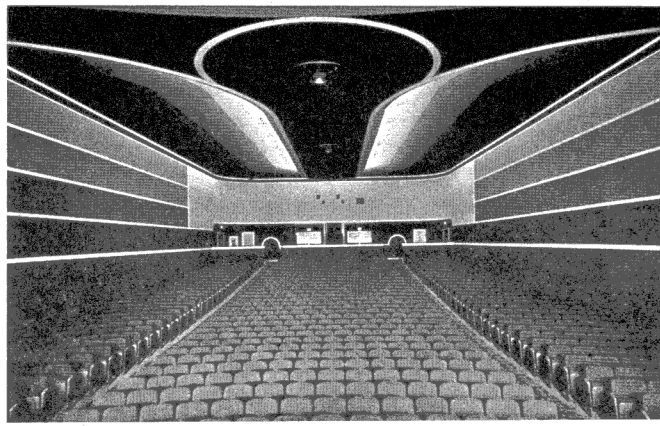
LESSON ND-32



SPRAYBERRY ACADEMY of RADIO

ESTABLISHED 1932

PUEBLO, COLORADO



Here is an excellent view of a modern theater interior. Note the small openings at the rear wall for the projectors. This is the Bard Theater in Louisville, Ky. Courtesy of Motiograph.

HOW SOUND IS EMPLOYED IN THE MOVIES

LESSON ND-32

This lesson has to do with sound reproduction as it is employed in the *movies*. The purpose of it is to instruct you in the general technique of *sound-on-film* reproduction. The lesson, however, is not intended to instruct you on how to be a movie projector operator for that is an occupation entirely different from one whose principal duty it is to work with radio and sound problems. In general, it may be said that sound reproduction from film is no different from that employed in reproducing sound from a microphone, phonograph, pick-up unit or from the output of a radio receiver once the sound energy equivalent is translated into electrical impulses. Just as soon as the sound track on the film is translated into electrical sound impulses, the same amplifying and reproduction problems must be handled as in any other type of amplifying system. Thus, there are involved the usual amplifiers, speakers, transmission lines, mixers, microphones, pick-ups and, in some cases, even a tuner type radio receiver. Some theaters have a mixing panel wherein it is possible to feed into the input of the amplifying system speech as for announcements (from microphones) the output of a pick-up for record reproduction and the output of a radio tuner for news broadcasts, etc. All this, of course, will be in addition to the usual channel for sound-on-film reproduction. So you may expect to encounter the usual repair problems common to all amplifying equipment if you work with sound-on-film equipment.

As a help in the study of this subject, a general knowledge of the methods of recording is necessary. You will be given a general, although not detailed, idea of these recording methods, and with this as a background, you should have no trouble in understanding the present reproducing systems in wide use.

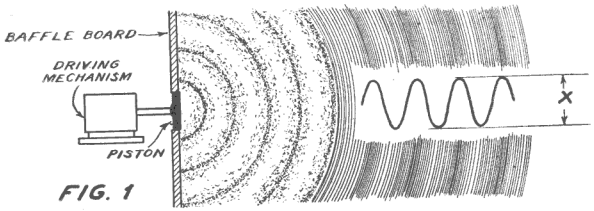


FIG. 1

Basically, the sound-on-film idea is to change sound waves such as music, speech, etc., into electrical impulses and record them in photographic form on film. In the reproducing system, the sound is taken from the film, changed into electrical impulses and then converted into sound again by use of speakers. In the case of radio, sound waves are changed to electrical waves at the transmitter and are converted to sound waves at the receiver. Motion pictures with sound have one additional intermediate step in the recording system. This additional step multiplies the necessity for good quality equipment both in the recorder and reproducer. The quality of the sound or audio frequencies reproduced must be *natural sounding* to the theater audience. If the voices of the screen actors are distorted or unnatural, the illusion of talking pictures is shattered, and the result is disappointing to the audience.

In order to better understand the art of motion picture sound work, it will be well to briefly refer to the characteristics of sound and sound waves. The usual definition of sound is considered to be a series of vibrations of the air of such frequency, or pitch, that it is *audible* to the human ear. Sound is also sometimes defined as an audio sensation on the ear produced by vibrations in the air striking the ear drum. Sound is produced when air is set into vibration by any means whatsoever, provided the frequency of vibration is such that it is audible. For purposes of illustration, refer to Fig. 1. This illustrates a piston driving mechanism which might well be a speaker.

If a piston, light in weight but several inches in diameter, is surrounded by a suitable *baffle board* several feet across and is set in rapid oscillating motion (vibration) by some external means, sound waves are produced. The air in front of the piston is compressed when it is driven forward, and the surrounding air expands to fill up the space left by the retreating piston when it is drawn back. Thus, there is a series of compressions and rarefactions (expansions) of the air as the piston is driven back and forth. Due to the *elasticity of the air,* these areas of compression and rarefaction do not remain stationary but move outward in all directions.

Sound is transmitted through the air, as stated in the foregoing, by alternate contraction and expansion of the air. This is a wave form such as is shown by the wavy line in Fig. 1. The loudness or amplitude of sound is directly proportional to the difference in pressure between the maximum pressure and rarefaction of the air. Or again, referring to the wavy line in Fig. 1, it is indicated by the distance X.

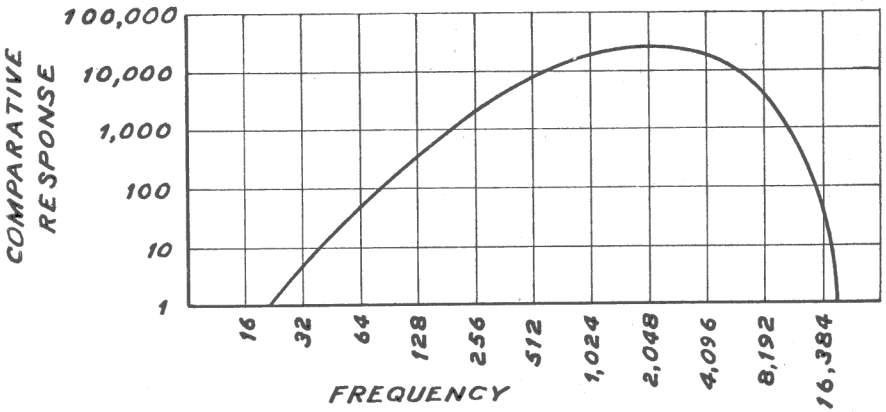


FIG. 2

The frequency of these vibrations determines the pitch of the sound. *Thus a note of a certain pitch has a certain frequency.*

The terms quality or tone are used in particular reference to music. You are familiar with the fact that a note of the piano or organ does not sound the same as the note of the same pitch on a cornet. This difference is due to the presence of overtones or harmonics. The harmonic frequencies or overtones are always some multiple of the *pitch frequency* and either of less or greater amplitude than the fundamental. The difference in tone of different instruments is caused by the amount of overtones present. The characteristic of overtones is also present in speech and thus explains the definite variation between voices of different people. Overtones are simply harmonics which have varying phase relations with respect to the fundamental tone.

The question then arises as to how high the frequency limit should be in motion pitcure work. Here the human ear must be considered. Figure 2 shows the response curve of an average human ear. The maximum response is between 500 and 7000 cycles per second. It is fairly safe, then, to say that if amplifiers in both the recording and reproducing system can adequately pass frequencies up to 8000 cycles they will deliver sounds which will sound fairly natural. Present day practice is to use an amplifier with a comparatively flat characteristic up to 10,000 cycles.

RECORDING

The moving picture you see on the screen is only an *illusion of a moving image.* Actually it is a presentation to the eye of the images of a series of snapshots taken in very rapid succession by the moving picture camera. The brain retains a memory impression for a short interval of time of that which is seen by the eye. The effect is known as *persistence of vision.* If a series of images, each one of which differs but slightly from the preceding image, is viewed in rapid succession by the eye, the brain retains an impression of the preceding image, blends it with the succeeding image *and there is the illusion of motion.*

Standard motion picture film is a strip of celluloid 1.375 inches wide by 0.0053 to 0.006 inch thick, one surface of which is coated with a photographic emulsion. On each side of the film is a row of perforated holes of a standard size. There are 64 perforations per foot on each side of the film. These perforations provide a means of positive feed of the film through the camera and projector.

In the making of motion pictures, the film, usually in rolls of 500 feet, is placed in a moving picture camera. The camera is provided with a mechanism whereby each ¾ inch length of film is successively exposed to the light illuminating the scene being photographed, thus taking a series of snapshots. The film moves through the camera at 90 feet per minute or 1½ feet per second so that 24 pictures are taken every second. (This speed of 90 feet per minute is always used when taking sound pictures. Silent pictures are usually taken at the rate of 70 to 80 feet per minute.) After being exposed, developed and dried, this film forms a negative from which a positive print is made on a similar strip of emulsion-coated and perforated film. *It is the positive print, on which the shadows and highlights appear in their natural order, that is used in projection.* In each foot of film there are 16 separate pictures or *frames* each one showing the subject or scene posed in a slightly different attitude as the action was caught by the camera. In a standard *silent film,* each picture of the film is ¾ of an inch high by approximately 1 inch wide. In standard *sound film,* because of space taken up by the sound track, the picture is only approximately ⅞ of an inch wide. There are four sprocket-hole perforations on each side of each picture.

With the advent of *sound motion pictures,* some method of placing the sound in synchronism with the picture had to be found. The first method tried was to record the sound on a disc very similar to a phonograph record. It differed in that it was 16 inches in dameter in place of the usual 10 or 12 inches and also ran at a speed of 33 1/3 RPM in place of 78 RPM. The slow speed and the large record allowed enough room to record enough sound for one reel of film. However, the difficulty of keeping the recording speed in synchronism with the camera as well as the limitations in frequency response of the records very soon caused this method to be thrown out in favor of film recording.

The sound track on the film is placed alongside of the picture, .027 inch inside of the sprocket-holes and .070 inch wide. Two fundamental types of film recording are used, namely, the *variable density* (Fig. 3) and the *variable area* (Fig. 4). The first step in recording is the transforming of the sound energy to electrical energy. This is done by means of a sensitive microphone of the velocity or ribbon type. The microphone does not supply sufficient energy to operate the recorder properly and *vacuum tube amplifiers* are required to increase the energy of the sound current before it is used to operate the recorder vibrator.

There are two different methods

FIG. 3

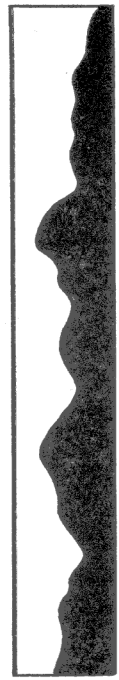
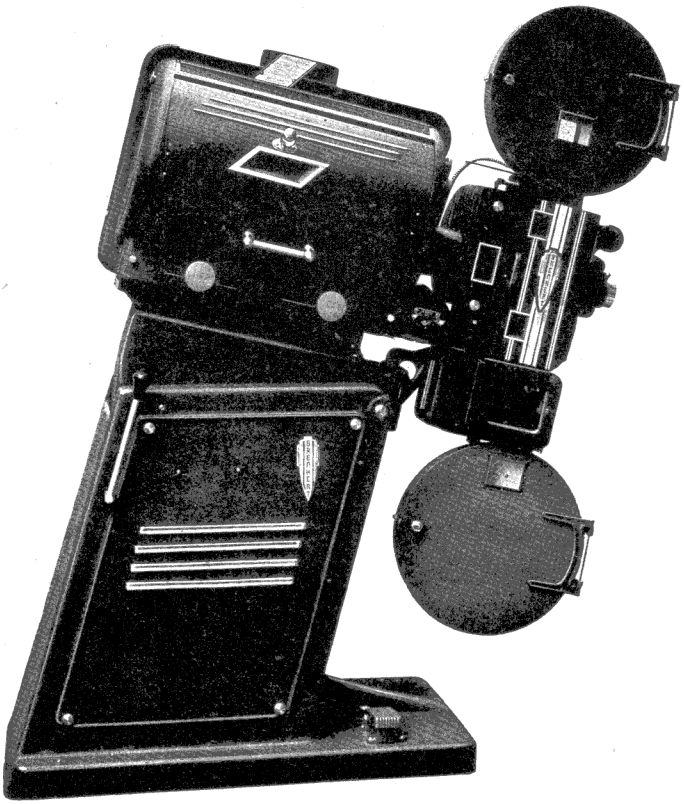


FIG. 4

of *variable density* recording. One method utilizes a variable intensity light called *Aeolight*. This light varies in intensity with the amplified sound currents and shines through a narrow slit onto the moving film which is kept running at a constant speed of 90 feet per minute. The width of the slit is about 0.0008 of an inch. When the film is developed after being exposed to the variable intensity light, the sound track will be made up of lines of varying density extending across the sound track, as shown in Fig. 3. If the frequency of the recorded sound is low, the width of the bands will be comparatively large, but if the frequency is high, the bands of light and dark will be very close together and may be hardly distinguishable. The variation of density between successive dark and light bands determines the amplitude of the recorded sound.

The other method of making variable density film recordings is by the use of a light valve. The light valve in this case varies the amount of light by the opening and closing of a slit. This slit is the space between two taut sides of a loop of wire suspended in a magnetic field. As the sound current passes through the loop, the loop opens and closes, passing varying amounts of light through it. This light is then focused by means of lenses on the moving film so as to form lines of varying width when the film is developed. Figure 5 shows the method used in variable area recording. In this system the source of light is kept constant, but the area of the sensitized film affected by the light is varied. Essentially, the system consists of a source of light, a mirror which is vibrated by the amplified sound currents and an optical system for concentrating the light into a very fine beam.

The vibrator is essentially a very sensitive galvanometer so constructed that the mirror follows faithfully all changes of sound current over a wide range of frequencies. Normally, the system is adjusted so that the reflected light exposes half of the sound track when no current is flowing. The sound signal, which is fundamentally alternating current, is allowed to flow through the vibrator, and the amplitude is adjusted so that the maximum swing will just cover the sound track. This adjustment is made by the aid of the viewing screens.



This view shows a modern complete projector mechanism. The upper and lower reels are entirely enclosed. The sound head unit is located between the two reels. Courtesy of Brenkert.

PROJECTION

To project the picture naturally, it is necessary that the picture be projected on the screen at the same speed as the pictures were taken. To obtain the illusion of motion, the pictures must be presented in rapid succession. (Sound pictures are projected at the rate of 24 per second.) This is accomplished by means of an intermittent movement which drives a sprocket called the *intermittent sprocket* so that the film is moved four sprocket holes (one picture frame), held stationary a short time, and then moved again to bring the next picture into place.

If the image of the film were projected on the screen while the film was in motion, the picture would be blurred by streaks of light up and down its surface. To prevent this blurring or streaking of the picture, a revolving shutter is used to cover the lens (or, in some cases, to cut off the light from the film) while the film is moving, thus hiding all film movement from the screen. This device usually consists of a circular disc of sheet metal with two opposite segments cut out leaving two solid blades.

This shutter revolves once for each complete cycle of the intermittent movement. Only one blade is necessary to cut off the light from

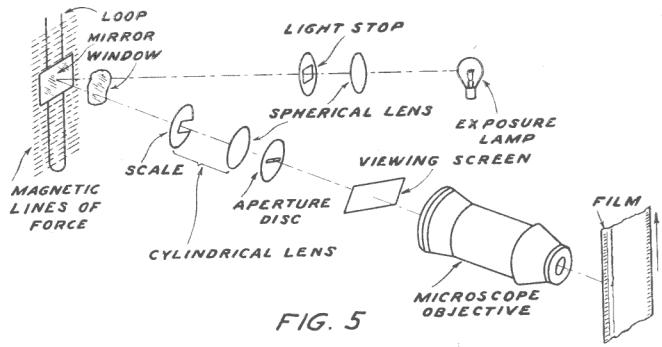


FIG. 5

the screen while the film is moving, but since light interruptions must be made at the rate of 36 or more per second to be invisible, a second blade is used to prevent the flickering of the light on the screen. (This second blade interrupts the light during part of the time that the film is held stationary.) These two blades are called the *cut-off* and the *flicker* blades respectively. The cut-off blade is usually a little wider than the flicker blade.

Figure 6 shows a schematic diagram of a projector mechanism. The mirror behind the projection lamp reflects the light emitted from the back of the lamp so that it reinforces the direct light, thus conserving the light energy of the lamp. The condenser lens in front of the lamp is for the purpose of concentrating the light on the aperture plate. The cooling plate is a piece of cast iron, usually ribbed, and with a hole slightly larger than the size of one picture frame. The purpose of this shield is to cut off the fringe of light not

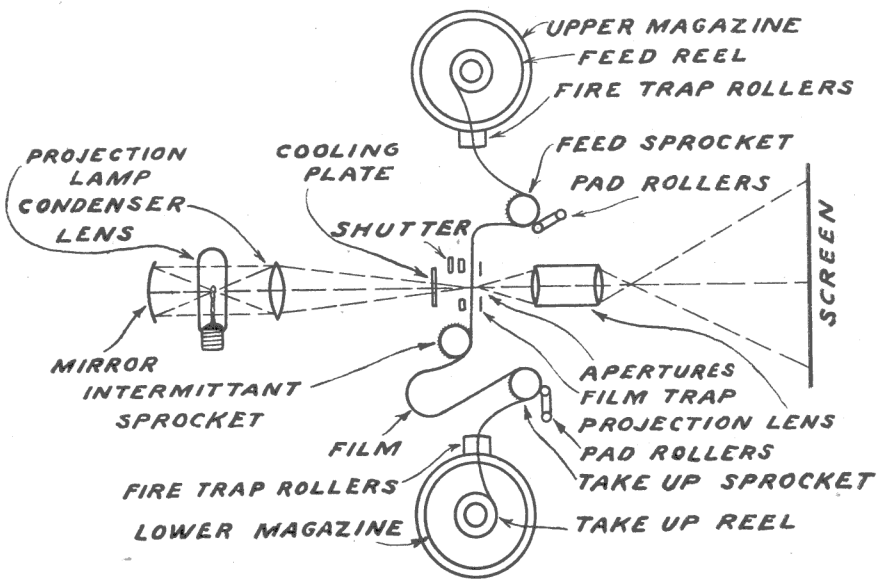


FIG. 6

used in illuminating the picture. The aperture plate is a metal plate with a rectangular hole the size of a film picture for passing the light on to the film. The purpose of the plate is to cut the light beam down to the exact size required for the illumination of the film picture. The fire shutter is used to close the aperture when the film speed drops below 50 feet per minute so as to protect the film (prevent fire) from the intense light of the arc lamp when the film is moving slowly or has stopped.

The upper or feed reel is mounted on a spindle within a film magazine and holds the film of the picture to be projected. There should be just enough friction to the rotation of this reel to prevent its feeding the film faster than is required. The two small rollers at the bottom of the upper magazine are firetrap rollers and are for the purpose of preventing any fire which may start in the projector from traveling up into the magazine. The upper feed sprocket unwinds the film from the upper reel and maintains a loop of film above the picture gate. This sprocket runs at a constant speed. The picture gate holds the film in focus at the aperture and consists of flat ridges, or tracks, on the light side and a pair of spring runners on the lens side. These runners hold the film against the aperture plate. They are backed with springs which keep a constant pressure on the film. The transmitter sprocket pulls the film through the gate exactly four sprocket holes at a time and remains stationary while the picture in front of the aperture is projected on the screen. Below the intermittent sprocket is another sprocket called the take-up sprocket which runs at a constant speed. The purpose of this sprocket is to keep the film moving at a constant speed and prevent the slight jerky motion imparted to the film by the lower reel from being transmitted to the intermittent sprocket. The lower, or take-up reel, like the upper reel, is mounted on a spindle in a fireproof magazine. This reel is driven by the projector drive mechanism through a clutch which permits slipping between the reel and drive mechanism so as to keep a constant pull on the film regardless of the diameter of the roll of film on the reel. The projector lens, which is mounted just in front of the picture gate, projects the highly illuminated film picture to the screen of the theater. The revolving shutter, which is mounted in front of the projection lens, cuts off the light from the screen while the film is moving in the picture gate and also serves to prevent flicker as described previously. This shutter is sometimes mounted between the projection lamp and the aperture plate but serves the same purpose regardless of where it is mounted.

REPRODUCTION OF SOUND

Figure 7 shows a typical turntable used in sound reproduction from records which revolve at 33 1/3 RPM. This is the earliest form of sound motion picture reproduction. In this particular type of installation, the only change necessary on the motion picture projector is the addition of a special driving motor to drive not only the projector but the turntable as well. The connection is

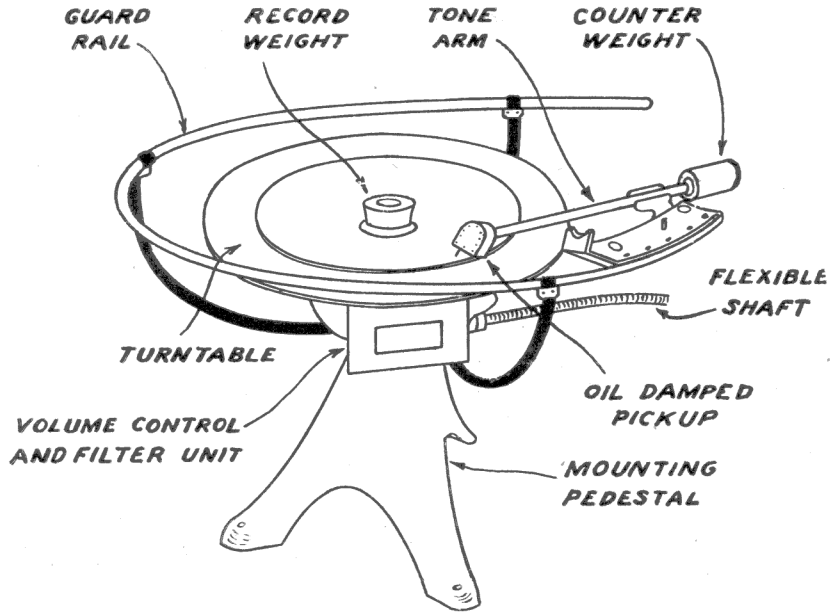


FIG. 7

made to the turntable through a flexible shaft. The turntable proper is driven from this flexible shaft through a worm and gear. To eliminate speed variation as much as possible, the turntable is driven through a heavy clock-type spiral spring immersed in a heavy damping oil. This tends to make the motion of the turntable constant with little or no variation in speed.

In order to *synchronize* the record and the film, special markings are necessary on both. The record has an arrow pointing to the exact point for synchronization. The film has a single frame with the word *Start* appearing on it. When the needle of the phonograph pick-up is placed at the arrow on the record and the *start* frame of the film is in the picture aperature of the projector, the sound will be synchronized with the picture.

This system proved very unsatisfactory for two reasons. The possibility of the picture and sound being out of synchronization is great. If the needle is only one groove out of its correct position, the illusion of a talking picture is destroyed. Secondly, unless given constant attention, the turntable develops variations in speed known as *wows*. Due to these objections, it is very seldom that installations of this equipment are used.

SOUND-ON-FILM

To reproduce sound from sound-on-film records, it is necessary to translate the photographic record of the sound track into sound. The first step of this process consists of translating the photographic variations into electrical variations. This is accomplished by passing the sound track of the film past a beam of light so that it varies the amount of light which

falls upon a photo-cell. (A photo-cell is a device which develops an electric current in proportion to the light falling upon it as will be explained in a later lesson. This translating device consists of a source of constant intensity light, an optical system which concentrates the light into a very fine beam the width of the sound track (0.001 of an inch thick) and a photo-cell. Figure 8 is a schematic diagram of such a device.

It is necessary for the light beam to be very thin if distortionless reproduction of the high AF frequencies is to be obtained. It can be seen from Fig. 8 that the film must be held exactly at the point of focus if this condition is to be met as a deplacement in either direction from this point will considerably increase the thickness of the beam striking the film. Another prerequisite for good sound reproduction is that the film must move past the light beam at an absolutely constant speed of 90 feet per minute. If the film speed varies, the pitch of the reproduced sound will vary (in a manner not in accordance with the original sound), causing a disagreeable sound effect described as a *wow*. The sound record translating device is called a *sound head* or *sound attachment* when it is attached to a machine designed for production of silent movies only. When the projector is designed to include the sound translating device, the device is called *the sound mechanism*. The sound head or mechanism is located so that it receives the film after it leaves the picture projection mechanism:

This sound mechanism consists of:

(a) An exciter lamp which provides a source of constant intensity light.

(b) An optical system which concentrates the light of the exciter lamp into a fine beam.

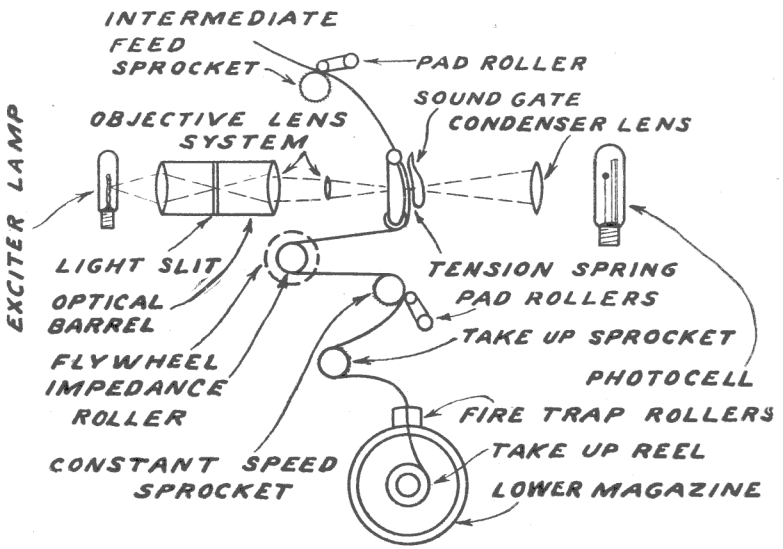


FIG. 8

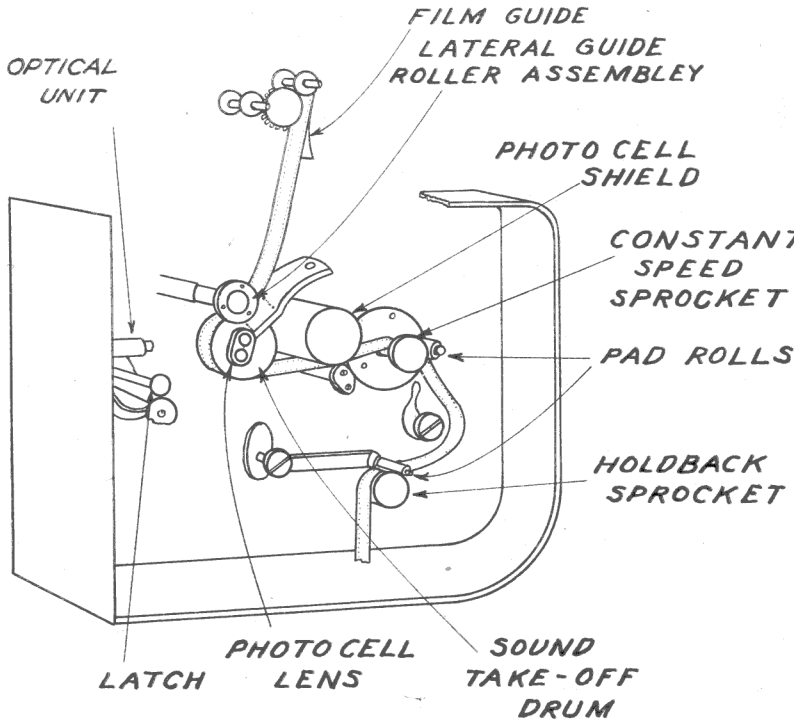


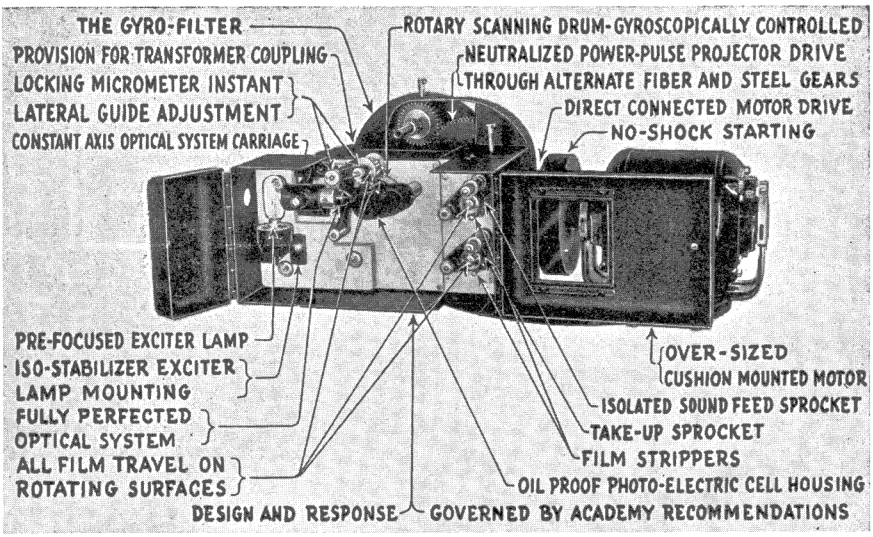
FIG. 9

(c) A sound gate which guides the film so that the sound track passes the light beam at the point where the beam is thinnest.

(d) A mechanical filtering device to insure an absolutely constant speed of the film as it passes through the gate.

(e) A photo-cell and its electrical circuit for translating the light variations into electrical AF variations.

The exciter lamps have a concentrated coil filament set in a horizontal position. These lamps are accurately made and require only a vertical adjustment in the socket. The optical system consists of a condenser lens, an optical slit and an objective lens system all mounted in a single barrel. The optical slit is adjustable to give a horizontal beam. The sound gate guides the film past the light beam and keeps the sound track in focus and aligned with the light beam. It consists of a curved surface over which the film slides, guide rollers which keep the film aligned and tension springs which keep the film pressed against the curved surface. The mechanical filtering device consists of a roller called an *impedance roller* attached to a small fly-wheel. It is mounted below the sound gate and is driven by the wrap of the film around the roller. The inertia of the fly-wheel tends to keep it running at a constant speed to the film. The gate aids in the filtering action by maintaining a constant drag on the film. The film is pulled over the roller by a sprocket running at a



Above is shown a typical sound machanism which is to be attached to the projector proper. Courtesy of the Ballantyne Co.

constant speed. This sprocket is commonly called the *constant speed sprocket*. Another sprocket called the *take-up sprocket* or *hold-back sprocket* engages the film after it leaves the constant sprocket. This sprocket serves to prevent the slightly jerking motion imparted to the film by the take-up reel from being transmitted to the constant speed sprocket.

Improvements have combined the sound gate and the impedance roller shown in Fig. 8 into one unit as shown in Fig. 9. In this case, the sound track on the film overhangs the sound take-off drum. The light, after passing through the sound track on the film, is reflected to the photo-cell by means of the photo-cell lens.

EXCITER LAMP

The life of an exciter lamp depends upon the value of current at which it is operated. If it is operated at a slightly lower current than that for which it is rated, its life will be considerably increased. On the other hand, a slight decrease in value of the current will considerably decrease the light output of the lamp. If the light output of the exciter lamp is decreased, it will be necessary to increase the volume level to maintain the desired output level; increasing the volume increases the background noises more than it does the desired signal, so that the best value of the exciter lamp current is one which is a compromise between the life of the exciter lamp and the background noise. Usually it will be found that the exciter lamp can be operated slightly below its rated value without increasing the background noise to an objectionable level. As the exciter lamp nears the end of its life, the inside of the bulb becomes darkened and the efficiency of the lamp is reduced. It is advisable to replace the lamps when they become excessively dark, and thereby avoid the possibility of an interruption

of the sound due to the burning out of the exciter lamp.

THE PHOTO CELL

A photo-electric cell is a device which varies in electrical resistance in proportion to the *amount of light* falling upon it. Although there are various devices to which the description might apply, the photo-electric cells used in sound-on-film projections, as made by the leading manufacturers of such equipment, make use of the fact that when light falls upon the surface of a metal, electrons are emitted from its surface. Although all metals emit electrons when subjected to light, only a few of them are affected by ordinary or visible light. The active metal used in the photo-cells is called cesium. When light falls on the metal, electrons are emitted from its surface in direct proportion to the amount of light falling on the surface of the metal—that is, if a certain amount of light falls upon the surface of the metal, a definite number of electrons will be emitted, and if the amount of light is doubled, the number of electrons will also be doubled. In order to make use of this fact, some method of collecting the electrons is necessary. To attain this end, a plate coated with the active metals is placed within a vacuum tube and an electrical connection is made from it to the out-side of the tube. Another conductor set in the proximity of the plate is also placed within the tube and has a lead brought out for electrical connection. The plate or metallic surface coated with the active metal is called the *cathode,* and the other conductor is called the *anode.* If the cathode is connected to the negative side and the anode is connected to the positive side of some source of DC potential (such as a battery), the anode will collect the electrons emitted from the cathode. Since the number of electrons emitted depends upon the amount of light falling on the cathode, the number of electrons collected by the anode will vary with the amount of light falling on the cathode. The electrons collected by the anode do not remain there but flow off immediately in the form of an electrical current through the external circuit and return to the cathode. Therefore, a varying amount of light falling on the cathode will cause a varying current in the external circuit. Figure 10 is an illustration of a photo-cell.

The foregoing description applies particularly to the commercial picture equipment marketed by RCA photophone. The other major equipment on the market at the

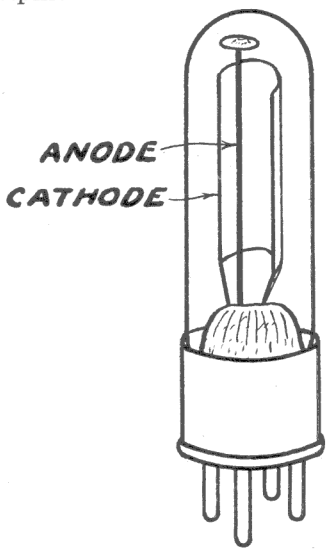
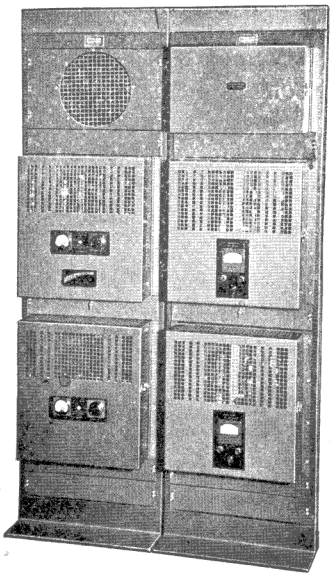


FIG. 10



The above view illustrates the amplifier set-up of a sound theater system. The grill opening at the top left is for the monitor speaker. These two panels contain both power unit and amplifier system. Each unit may be quickly removed from the rack for repairs. Courtesy of Motiograph.

present time is that marketed by licensees of the Western Electric Company. Basically, the reproducing systems are substantially the same. However, methods of amplification and reproduction differ in several major points. These variations will be pointed out later on.

PHOTO-CELL CONNECTIONS

In earlier models of sound motion picture equipment, the photo-cell was connected to the amplifier through a photo-cell transformer. This transformer was not a step-up transformer but a step-down transformer. The reason for this was that the photo-cell output circuit is of high impedance. If this circuit is of appreciable length without careful shielding a great deal of external noise is picked up. This pick-up signal in some cases may exceed the signal from the photo-cell. However, when a step-down transformer is used, the impedance of the line is reduced to a point where very little pick-up of external noise is experienced.

Figure 11 shows a circuit using such a system. Note there are provisions for two photo-cell units—the other one will be in the second projector. The *fading switch* is also shown in Fig. 11. The question of *fading* switches or *sound*

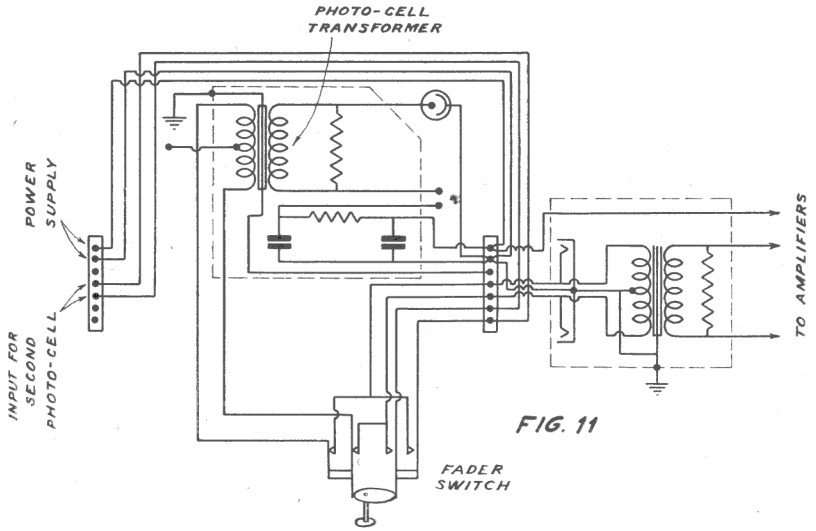


FIG. 11

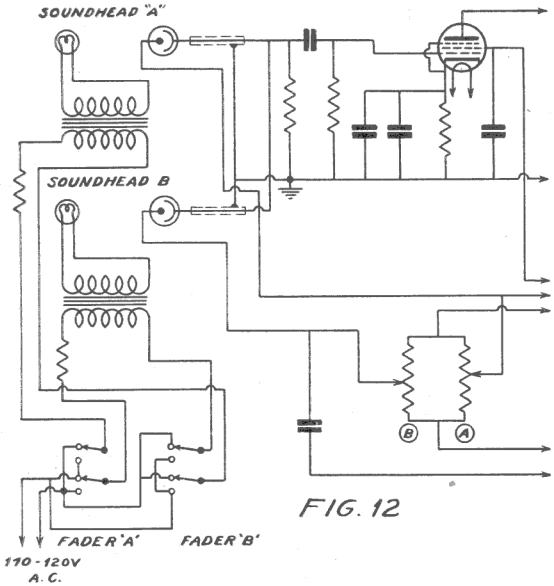


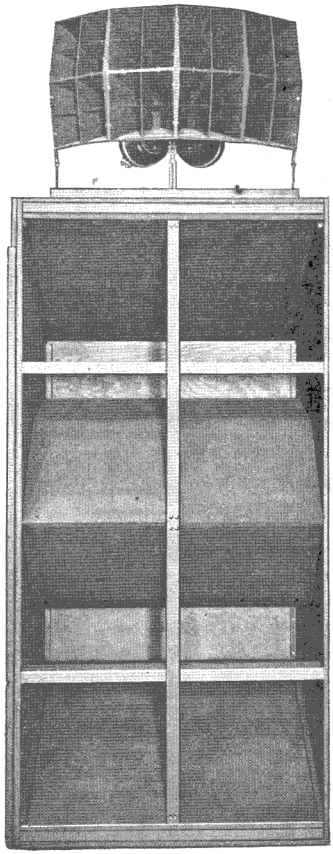
FIG. 12

changeover switches will be taken up a little later.

The latest designs of equipment have eliminated the photo-cell transformer. Extensive and exhaustive experimental work has developed a special low capacity transmission cable which allows the photo-cell current to be carried directly to the amplifier without special coupling transformers. Such a circuit is shown in Fig. 12.

The Western Electric Equipment differs quite radically from the foregoing. In place of a transformer in the soundhead, coupling the photo-cell to the amplifier, WE equipment actually has a single stage amplifier mounted in the soundhead. This unit is resistance coupled to the photo-cell. A fundamental circuit of this type is shown in Fig. 13.

This arrangement requires that the amplifier be extremely well cushioned. If the amplifier is not cushioned, all the mechanical vibrations in the projector will be transmitted to the amplifier. They will, in turn, be amplified through the regular amplifier, and, by the time the speakers are reached by the signal, the noise will be greater than the signal from the film. However, the advantage of a comparatively low impedance line to the main amplifier, which picks up little or no interference, off-sets the necessity for cushion mounting the soundhead amplifier.



This view shows a typical speaker arrangement for the modern theater. The unit on top is a high frequency multi-cellular horn with 90 degree horizontal and 45 degree vertical coverage. The larger baffle unit below employs 15 inch dynamic units for low frequency reproduction. Courtesy of Motiograph.

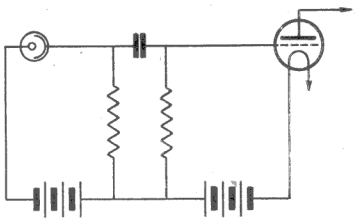


FIG. 13

In order to make a complete motion picture, not less than six thousand feet of film, and, in some cases, as much as ten to twelve thousand feet of film are required. The greatest amount of film wound on one reel is two thousand feet. Now in order to complete the illusion of motion pictures, it is necessary that the motion be continuous. That is, there must be no noticeable break between scenes when changing from one reel of film to the following reel. To accomplish this purpose, *two projectors are used* in the projection booth. In front of each projector are two openings. One for the operator to watch the picture on the screen, the other, known as the picture port, through which the picture is projected onto the screen. Over these openings are movable doors known as *dowsers*. These dowsers are either mechanically or electrically interlocked so that when one is opened the other is closed.

The following description covers the operation of changing from one projector to the other. Part No. 1 of the picture is placed in one projector and threaded so that the *start* frame of the film lines-up in the aperture of the film trap. At the start of the show, the projector motor is started, and when it is up to speed, the dowser is opened. When the picture appears on the screen, the sound is faded in so that it may be heard. While part No. 1 is running through one machine, part No. 2 is threaded into the other machine. When part No. 1 is nearly through, the motor cue will appear. (This point is determined by the action taking place in the picture or by a marking on the film which is projected on the screen. At the motor cue, the second projector is started, and at the changeover cue, the dowser of the outgoing machine is closed and the dowser of the incoming machine is opened. Immediately after the changeover, the sound is faded from the outgoing projector to the incoming projector. When all of the film is wound on the outgoing take-up reel, the projector is stopped and threaded with part No 3 of the picture and the same procedure is followed through. At the end of the picture, the film is run through until the changeover cue is indicated, at which time the dowser is closed and the sound faded. If the changeover and fadeovers are properly timed, the show will be continuous (without a break), but to obtain perfect timing, considerable skill is required. A new picture should be rehearsed to perfect the timing of the changeover and fadeovers. If film with standardized cues are used, the timing will not need to be rehearsed after the proper timing has once been determined for the standardized cues, but each type of machine will require its own particular timing which can only be determined by rehearsals. No standardization of cues can be adapted to all types of projectors without rehearsals. Perfect timing of the picture cannot be obtained without skillful

operation and attention to details.

At this point, you should become acquainted with the definitions of several terms used in sound motion picture projection. These follow:

Changeover—the word changeover is used to describe the operation of changing the picture projection from one projector to another.

Fading—the word fading is used to describe the operation of changing the sound reproduction from one projector to the other. The switch used to accomplish the operation is called a *fader-switch.*

Cue—the word cue means some sort of an indication, as a signal, for a certain operation.

Motor Cue—the motor cue is a signal for starting the motor of the incoming projector.

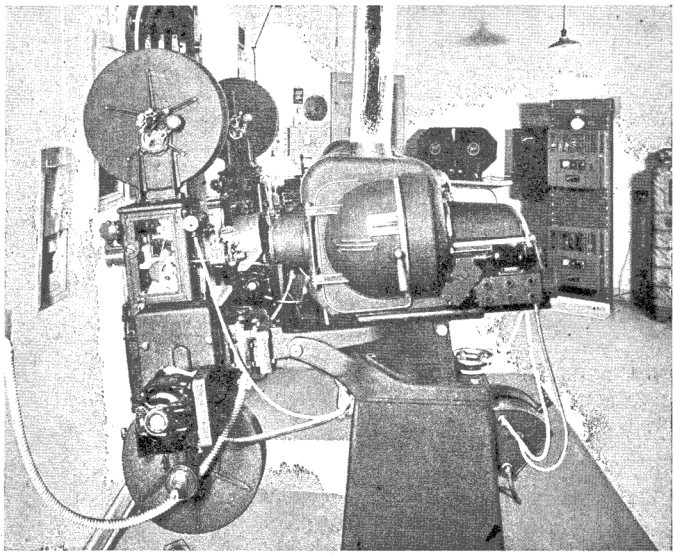
Changeover Cue—the changeover cue is a signal for making a changeover of the picture projection.

Significant Sound—the significant sound is a signal which has a bearing on the picture, such as dialogue, as contrasted from incidental sound such as music or ordinary sound such as traffic noise which accompanies the action of the picture but has no particular significance.

FADING OF SOUND

As in the case of changeover in pictures, fading of sound must be accomplished with a minimum of noticeability to the audience. Two circuits for fading sound are shown in Figs. 11 and 12.

The circuit shown in Fig. 11 gives the wiring of a unit designed where all fading of sound is done at one projector. If you will follow the circuit through, you will find that the fader switch is actually a double pole, double throw switch. This particular switch is constructed so that when transforming sound from one projector to



Above is shown the projection room in the Ellicott Theater at Ellicott City, Md. Note two projectors are used. The amplifier rack is shown at the right in the rear. Courtesy of Motiograph.

another, one circuit is made before the other is broken. As all sound fading in pictures is done when no sound is necessary for the picture, the momentary paralleling of the two projectors during the fadeover is not objectionable. Often this fading switch is placed on a panel at the front of the projection booth.

Recently, it has been found that there is enough time in fading sound from one projector to the other to use the exciter lamps. That is, in fading from projector A to projector B, the exciter lamp of projector A is turned off and the exciter lamp of projector B is turned on. Figure 12 shows a circuit of this type. If you will trace the circuit you will find that projector B is in operation. At the time of fadeover, the usual procedure is for the operator to be stationed at the incoming projector, in this case projector A. At the fadeover cue, he throws the fading switch on that projector. By tracing the circuit, you will find this operation has turned on the exciter lamp on projector A and turned off the exciter lamp on projector B. Gong further, and fading from projector B, and using the fading switch at projector B, you will find that again the exciter lamp at projector B is turned on and the exciter lamp at projector A is turned off.

Due to the fact that it is difficult to obtain two photo-cells with identical gain or response characteristics, some provision must be made to compensate for differences in sound level. If this is not done, the sound of one projector will be lower than the sound from the other. This difference will be noticeable when changing over from one projector to the other. Figure 12 also gives a method of accomplishing this compensation. You will note that one side of each photo-cell is connected together and leads to the grid of the first tube. The other side of each photo-cell is connected to a different potentiometer at (A) and (B). The potentiometers control the voltage applied to each photo-cell, and in this way the output of each photo-cell. By placing a film in both projectors and running them at once and fading from one to the other, it is possible to adjust the output of each projector until they are equal.

AMPLIFIERS

The amplifier is perhaps the most important part of sound-on-film equipment. This is not true because other parts can be eliminated but rather because the amplifier is the only point at which the frequency response of the overall equipment can be controlled.

As stated previously, the illusion of sound pictures depends upon natural sounding tones and speech which reach the ears of the audience. The frequency response of the film, the photo-cell system and the speaker are more or less fixed. That is, their frequency response is always the same and compensation for their deficiencies cannot be readily corrected within themselves. For this reason the amplifier is not designed as a unit in itself insofar as frequency characteristics are converned. On the contrary, the design of the amplifier takes into consideration every detail of the balance of the equipment.

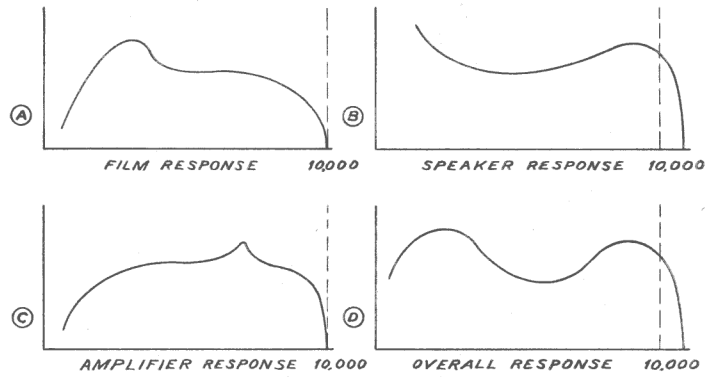


FIG. 14

Figure 14 shows typical frequency response curves of the various component parts of sound-on-film picture equipment. Figure 14A shows the frequency response of the film only. Note the decided drop in output at the higher frequencies. This curve is an average curve and is shown only for comparison. Figure 14B shows a typical speaker response curve. Actually this curve consists of many sharp peaks, but, as they cover single freqeuncies, they do not affect the overall characteristic and are not considered. Figure 14C shows an average amplifier characteristic. The deficiencies of the film and the speaker have been considered as well as the human ear. Figure 14D gives the final overall characteristic of the full equipment from film to speaker. The low and high frequencies have been stressed as it has been found that the human ear is insensitive in an increasing amount as the frequency decreases below 150 cycles and above 5000 cycles.

Figure 15 shows an amplifier with a small power output and is designed for small theaters seating less than 500 persons. As a rule, economy is necessary in these small

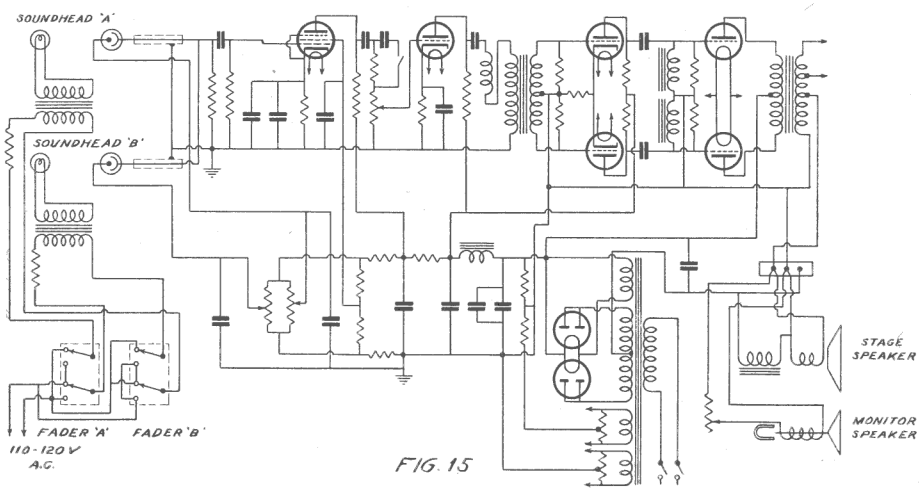


FIG. 15

installations. This amplifier is inexpensive and easily supplies all the power necessary to fill a small theater. Four stages of amplification are used, the first two stages being single tubes and the last two stages being push-pull. You will note that resistance coupling is used almost entirely. The only exceptions are those between the second and third stages and the amplifier output transformer. Resistance coupling is used because of the good frequency response possible with this type of amplifier.

The volume control is placed in the grid circuit of the second stage. As no DC current passes through this circuit, little or no trouble is experienced due to noisy controls. It is of relatively high resistance, as it is in the grid circuit, being from .5 to 1 megohm. You will note that although the second and third stages are transformer coupled, the plate circuit of the second stage is fed through a resistor and the transformer is blocked from DC current by a series condenser. The purpose of this method of coupling is explained as follows: When DC current passes through a transformer, extreme care must be taken in the design to make certain the transformer core does not become saturated under large audio signals. To do this, certain changes are made in the core, such as the use of air gaps, to eliminate this possible saturation. Such changes, however, tend to reduce the high frequency response of the transformer. However, if no DC is present in the primary of the transformer, it is easily possible to design the transformer to have a frequency characteristic extending as high as 15,000 cycles.

You were told in the first discussion regarding amplifiers that in order to have the sound response appear natural to the audience, it was necessary to have the amplifiers compensated. Compensation means the increase or decrease of amplification of a certain band of frequencies. In this particular amplifier, compensation is provided in the grid stages of the two push-pull stages. The combined inductance and resistance in the grid circuit of the last stages is a *booster* for the low frequencies.

In this particular equipment, the field coil of the stage speaker is a part of the rectifier filter system. As one side of the voice coil circuit and one side of the field coil circuit are grounded, they are combined, and it is only necessary to run three wires from the amplifier to the stage speaker.

All projection booths are made soundproof to a great extent in order that the noise of the projectors will not annoy the theater audiences. This same soundproofing prevents the operator from hearing the sound put forth from the stage speaker. In order that the operator will know the sound equipment is operating correctly, a monitor speaker is placed in the booth and is operated in parallel with the stage speaker. This speaker is of the permanent magnet type, and a volume control is placed in its circuit so that its volume can be independently controlled.

As this amplifier is fundamentally a high frequency unit, it is imperative that the plate supply of the first stages be extremely well

filtered. In the first designed sound picture equipment, the first stages of amplification were supplied from "B" batteries. However, later designs are all AC operated. In the circuit of Fig. 15, you will note that the first stage plate circuit is supplied through a three stage induction, resistance capacity filter. For successive stages, the necessity for well filtered DC grows less important.

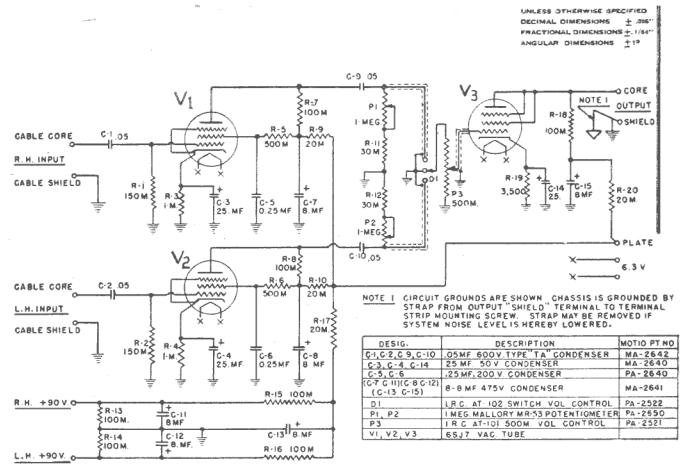
The amplifier is often mounted on the wall of the projection booth, between the two projectors. This minimizes the wiring necessary to the stage and monitor speakers and places the volume control close to the operator. In addition the low capacity cables from the soundhead to the amplifier are as short as possible. In larger installations, the amplifier equipment is rack mounted, and the amplifier rack is placed at the back or side of the projection booth. All component parts of the amplifier are made in individual units for ease in repair and replacement. The size of these amplifiers depends upon the size of the theater. It is only necessary to add individual amplifier units to increase the power output of the amplifier.

The voltage amplifier is, as its name implies, simply a high gain amplifier to build up the voltage. No attempt is made for high power output. The output of the last stage of this unit must be sufficient to swing the grids of the power amplifier stage as it is this stage that develops the power. This stage has two 50 type tubes in push-pull. It is sometimes found that 50 watt tubes are used in this stage. Of course, the output from amplifiers using these large tubes is in the neighborhood of from 40 to 80 watts of undistorted audio power depending upon whether one or two power amplifiers are used.

The stage speaker field supply units furnish the power to the fields of the stage speakers. These power supply units may be either tube rectifiers or dry disc copper-oxide rectifiers. They are not always located at the amplifier, but they may be located at or near the speakers. In either case, it is necessary to run the same number of wires from the projection booth to the speakers. In one case, the wires carry the actual field supply. When the supply units are located near the speakers, these wires carry the control current for turning the power supply to the units on and off.

Figure 16 shows a more detailed electrical system for sound motion pictures. You will note several things in common for this equipment. First, each unit is complete within itself. That is, each unit has its own power supply. This reduces the number of leads to be connected between each unit as well as simplifying service. If any one unit goes bad, it is a simple matter to remove the unit and replace it with a new unit. You will note also that two power amplifiers are used.

As you have already considered the forms of photo-cells coupling, it will not be necessary to consider this particular equipment in that respect. However, the fading system is somewhat different from usual. Fading is done by means of *relays* located in the sound control



NOTE 1 CIRCUIT GROUNDS ARE SHOWN CHASSIS IS GROUNDED BY STRAP FROM OUTPUT "SHIELD" TERMINAL TO TERMINAL STRIP MOUNTING SCREW. STRAP MAY BE REMOVED IF SYSTEM NOISE LEVEL IS HEREBY LOWERED.

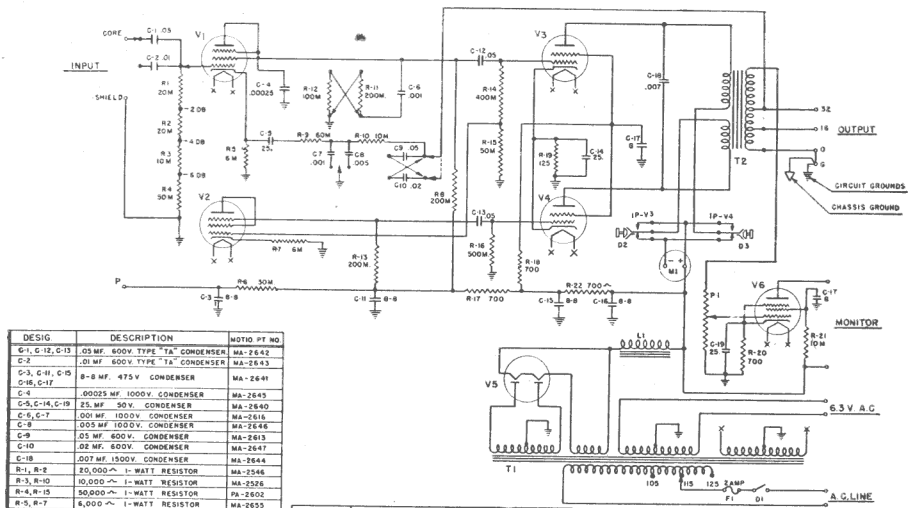
DESIG.	DESCRIPTION	MOTIO PT NO
C-1, C-2, C-9, C-10	.05 MF 600 V TYPE "TA" CONDENSER	MA-2642
C-3, C-4, C-14	25 MF. 50 V CONDENSER	MA-2640
C-5, C-6	.25 MF. 200 V CONDENSER	PA-2640
(C-7, C-11) (C-8, C-12) (C-13, C-15)	8-8 MF 475 V CONDENSER	MA-2641
D1	I.R.C. AT-102 SWITCH VOL. CONTROL	PA-2522
P1, P2	1 MEG. MALLORY MR-53 POTENTIOMETER	PA-2650
P3	I R C AT-101 500M VOL. CONTROL	PA-2521
V1, V2, V3	6SJ7 VAC. TUBE	

DESIG.	DESCRIPTION	MOTIO PT NO
R-1, R-2	150,000 OHM 1/2 WATT RESISTOR	PA-2645
R-3, R-4	1,000 " " " "	MA-2641
R-5, R-6	500,000 " " " "	PA-2535
R-7, R-8, R-13, R-14 R-15, R-16, R-18	100,000 " " " "	MA-2534
R-9, R-10, R-17, R-20	20,000 " " " "	PA-2643
R-11, R-12	30,000 " " " "	PA-2644
R-19	3,500 " " " "	PA-2642

This is the circuit of the PA-7505-A voltage amplifier of the Motiograph Co., manufacturers of projection equipment. It consists of individual input stages for each of two sound heads. A common output stage is used to feed the main amplifier.

units. These units are mounted on the front wall of the projection booth on the operating side of each projector. The relays are operated by means of momentary contact key switches, also mounted in the sound control units. Power for the operation of the relays is obtained from the speaker field supply panel.

The fader system is really a selector system. That is, to fade sound from one projector to another, the key switch must be operated at the projector from which sound is desired. Operating this switch energizes the proper relay which transfers the sound input connections to the proper projector. The relay contacts are so connected that when a relay is energized, one set of its contacts remains closed until broken by the opposide fader switch. The fader switch consists of four pairs of contacts all operated by the same key. Two pairs are for closing the coil circuit of one relay and opening the coil circuit of the other relay. The other two pairs of contacts are used for short circuiting the speaker voice coils. Short circuiting the speaker voice coils when fading eliminates any possible click or noise from annoying the theater audience during the changeover period. The special input circuit is controlled by a separate special input switch. This circuit is connected to the primary of the input transformer. The switch is so constructed that the special input circuit connection is made before the photo-cell circuit is broken. You will also note that a low impedance line is used between the soundhead and the amplifier, a three stage high gain unit. The line is coupled to the first stage by a step-up transformer. The first and second stages



DESIG.	DESCRIPTION	MOTIO. PT. NO.
C-1, C-12, C-13	.05 MF. 600V. TYPE "TA" CONDENSER	MA-2642
C-2	.01 MF. 600V. TYPE "TA" CONDENSER	MA-2643
C-3, C-11, C-15 C-16, C-17	8-8 MF. 475V CONDENSER	MA-2641
C-4	.00025 MF. 1000V. CONDENSER	MA-2645
C-5, C-14, C-19	25. MF. 50V. CONDENSER	MA-2640
C-6, C-7	.001 MF. 1000V. CONDENSER	MA-2616
C-8	.005 MF. 1000V. CONDENSER	MA-2646
C-9	.05 MF. 600V. CONDENSER	MA-2613
C-10	.02 MF. 600V. CONDENSER	MA-2647
C-18	.007 MF. 1500V. CONDENSER	MA-2644
R-1, R-2	20,000 Ω 1- WATT RESISTOR	MA-2546
R-3, R-10	10,000 Ω 1- WATT RESISTOR	MA-2526
R-4, R-15	50,000 Ω 1- WATT RESISTOR	PA-2602
R-5, R-7	6,000 Ω 1- WATT RESISTOR	MA-2655
R-6	30,000 Ω 1- WATT RESISTOR	PA-2605
R-8, R-11, R-13	200,000 Ω 1- WATT RESISTOR	MA-2657
R-9	60,000 Ω 1- WATT RESISTOR	MA-2656
R-12	100,000 Ω 1- WATT RESISTOR	MA-2542
R-14	400,000 Ω 1- WATT RESISTOR	MA-2636
R-16	500,000 Ω 1- WATT RESISTOR	MA-2659
R-17, R-18, R-22	700 Ω 1- WATT RESISTOR	MA-2654
R-19	125 Ω 20- WATT RESISTOR	MA-2651
R-20	700 Ω 10- WATT RESISTOR	MA-2652
R-21	10,000 Ω 10- WATT RESISTOR	MA-2653
D-1	S.P.S.T. TOGGLE SWITCH	MA-2521
D-2, D-3	PUSH BUTTON SWITCH	MA-2605

DESIG.	DESCRIPTION	MOTIO. PT. NO.
P1	POTENTIOMETER 200,000 Ω	MA-2525
M1	METER 0-200 MA	MA-2636
T1	POWER TRANSFORMER T-47868	MA-2637
T2	OUTPUT TRANSFORMER T-47870	MA-2638
L1	CHOKE COIL T-47869	MA-2639
V1, V2	6SJ7 VAC. TUBE	
V3, V4	6L6G VAC. TUBE	
V5	5Z3 VAC. TUBE	
V6	6K6 VAC. TUBE	
F1	FUSE 2-AMP	MA-2681

NOTES
1. WIRES ENDING THUS —► ARE TO BE CONNECTED IN FIELD AS REQUIRED. SEE INSTALLATION INSTRUCTIONS

Schematic diagram of Motiograph-Mirrophonic MA-7505-A Amplifier

The above shows the main or power output amplifier of the Motiograph amplifier. It is used with the PA-7505-A unit for a total output of 20 watts—sufficient for a seating capacity of from 800 to 1000 people.

are coupled by resistance-capacity circuits. A high resistance potentiometer, about one-half megohm, is provided in the grid circuit of the second stage to vary the input voltage applied to the grid, thus controlling the output volume on the entire equipment. The output of the second stage is resistance-transformer coupled to the push-pull output stage of the voltage amplifier. An output transformer couples the voltage amplifier to the line and to the power amplifier.

A filter unit consisting of inductance and capacity is used in the plate circuit of the second stage to provide a sharp frequency cut-off at approximately 9500 cycles. Frequency cut-off at 7000 cycles can be obtained by paralleling the small condenser by another small condenser.

Plate voltage for the voltage amplifier tubes and polarizing voltage for the photo-cells are supplied by a single full-wave rectifier tube and a filter arrangement all located in the voltage amplifier unit. Voltage is also available for operating a microphone if an announcing system is used with the reproducing equipment.

A potentiometer is provided in the polarizing voltage circuit for each photo-cell so that the photo-cell output of the soundheads may be equalized. These potentiometers are located in the sound control units at each projector. The extra resistors in each circuit are used to make the load on the sup-

ply circuit always the same regardless of whether two, three or four projectors are used.

A rather unique remote volume control is shown in this equipment. A small condenser type of motor is geared to the volume control shaft. This motor, the circuit for which is shown below the voltage amplifier circuit in Fig. 16, is controlled by push buttons located on the sound control units near each projector. It is possible to control this volume from the auditorium of the theater, if so desired, by adding a push button station at some convenient point in the theater.

The power amplifier consists of a single push-pull stage of power tubes. Plate current is supplied by two half-wave rectifiers connected for full-wave rectification. The input transformer is matched to the line from the output of the voltage amplifier. The output transformer of the power amplifier has a tapped secondary. These taps provide sufficient different impedances to care for a number of stage speakers. The connections shown are for two speakers. The tapped inductances used are for matching loads. In some cases, it is desirable to operate some of the speakers at a high sound level. For instance, those operated for directing sound to the balcony in a large theatre are operated 2 to 4 db higher than those for the lower floor.

The speaker field supply units shown are operated by dry disc rectifiers. The rectifier is connected in a bridge circuit, each unit having sufficient capacity to supply field voltage and current to four speakers. In interconnecting the various units on the amplifier racks, extreme care must be taken that input and output circuits are kept well apart. A great deal of trouble can be experienced when these two circuits are coupled by being too close together.

SPEAKERS

The last step taken in reproducing the recorded sound is by means of the speaker. One or more of these units are mounted in the rear of the picture screen, and they are so located as to direct the sound produced by them through the screen to all parts of the area occupied by the audience. In some cases, especially in large theatres, the speakers are built into the walls and the ceiling surrounding the screen. This is done for two purposes. It removes the necessity of removing the speakers from the back of the screen when stage shows are presented, and it also allows the use of the speakers for sound reinforcing. In the latter case microphones pick up sound on the stage, and it is amplified through the regular amplifier equipment and reproduced through the same speakers that are used for the sound motion pictures.

A speaker must be capable of setting up vibrations in the surrounding air which will range in frequency from about 50 to 7,000 cycles per second if natural reproduction is to be obtained. The air can only be set into vibration if some solid object is moving it, thus causing these movements to be transmitted to the air. Therefore, the function of a reproducer is to set a body which is in contact with the surrounding air into rapid vibration so that its vibrations corre-

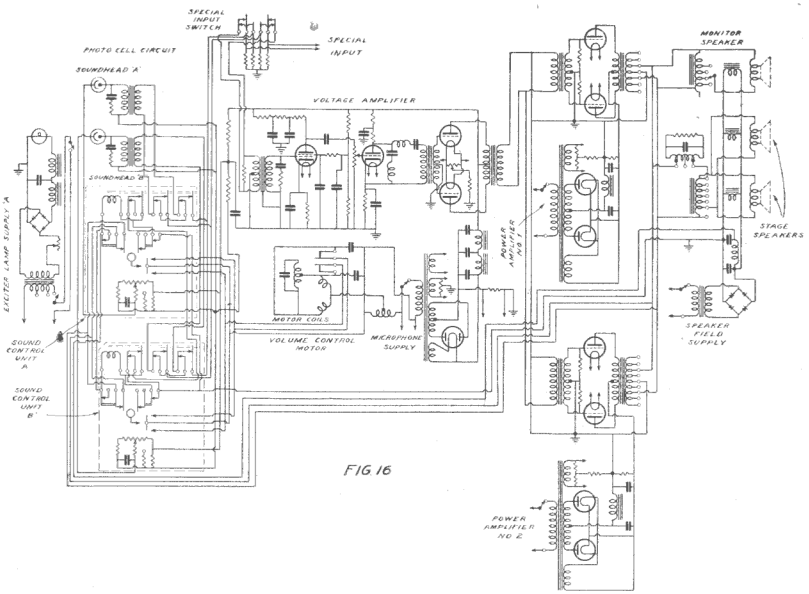


FIG 16

spond at all times to the frequency of the original sound.

To produce the desired volume of sound, the vibrating mechanism must have a large surface because the distance through which it moves is limited; and, in addition, the driving mechanism for the reproducers must be capable of changing the electrical sound current into mechanical force without introducing any appreciable vibration or distortion.

The ideal mechanism for a faithful sound reproducer will consist of a very light weight piston (diaphragm) which moves as a whole. The action of such a device is described earlier in this lesson. It is not practical to construct a mechanism as shown in Fig. 1 which would be sufficiently light and rigid, but a cone shaped contrivance, as used in common speakers, answers the purpose admirably because it can be made both light and rigid.

There are two types of speakers used in present day theatre installations. These are the cone type and the diaphragm type. Basically, these both operate on the electrodynamic principle. The RCA Photophone equipment uses the cone type exclusively while the WE equipment uses the diaphragm type speaker. On some equipment, WE uses the cone type speakers for the low frequencies and the diaphragm type speaker for the high frequencies.

The cone type speakers consist essentially of two main parts; an iron housing or *pot,* which is magnetized by a field winding and a movable cone on which is mounted a *voice coil.* The magnetic field is produced by a powerful electromagnet made up of a large coil of wire wound on an iron core and enclosed in the iron housing in such a way that the housing itself is a part of the electromagnetic circuit The purpose of this is to bring two

magnetic poles very close to each other. A study of Fig. 17 will show how this is accomplished. The left end of the core is one pole, while the other pole is the left end of the iron housing surrounding the end of the core. Between them is located the voice coil, a sectional view of which is shown. By bringing the poles together in this manner, the lines of force from one pole to the other *are concentrated in a very small area.*

The cone is about six inches in diameter at its outside edge, or mouth, and is made of heavy paper impregnated with a moisture resisting compound. It is corrugated in concentric rings to improve the quality of reproduction. At the apex of the cone a cylindrical fiber ring about an inch in diameter and one-quarter inch wide is cemented to the paper of the cone. On this is wound the *voice coil,* a small coil of fine wire which is the end of the circuit carrying the amplifier output. This ring, with the coil on it, is centered into position in the air gap between the two poles of the field. It is held in place by a screw passing through the center of a circular disc of fiber called the center spider. This fiber spider has curved sections cut out of it to increase its flexibility. The outer edge of the cone is cemented to a very light, thin, flexible ring of leather, which, in turn, is secured to the cast aluminum flange. When supported in this way, the cone is free to move in one plane, along its axis, due to the flexibility of the spider and leather ring supporting the cone. This allows the voice coil to move in and out along the air gap thus producing sound.

The moving coil is carefully centered in the air gap so that no part of it may touch either pole piece. This setting is clamped or held in place by the centering screw. If the coil should touch either of the pole pieces at any time that the speaker is operating, the movement of the cone will be interrupted and distortion will result. Dirt in this

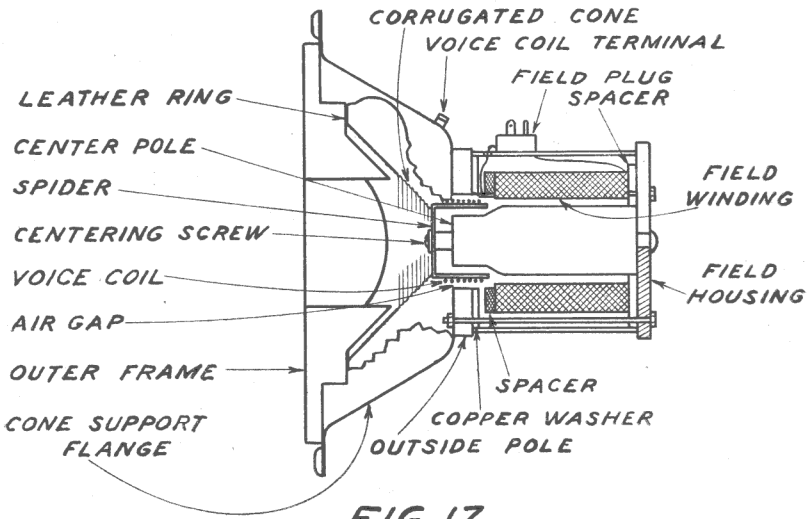


FIG. 17

recess would cause the same trouble. The speaker units are totally enclosed to prevent dirt and water from entering.

The dynamic speaker operates on the same fundamental principles as those underlying the action of an electrical motor. If a coil or winding carrying an electric current is placed in a magnetic field, this coil has a tendency to move in a direction at right angles to the lines of force in the field, the amount of movement being proportional to the number of lines of force and the amount of current flowing in the coil. The direction of movement depends upon the direction of flow of both the lines of force and the current in the coil. The lines of force of the field are always in the same direction because the field coil is energized with direct current. When alternating currents of various frequencies are sent into the voice coil of the dynamic reproducer, the pulsations in one direction move the coil outward, then the pulsations in the other direction send the coil inward. Figure 18 shows how this action takes place. The arrows representing the lines of force always flow from the same pole, but the direction of current in the voice coil changes constantly. Figure 18A shows the current and consequently, the motion of the cone in one direction, and Fig. 18B shows it in the other direction.

All types of speakers are equipped with directional baffles of either wood or metal. These baffles increase the efficiency of the speakers, directing the sound energy in the direction desired. The placing of the speakers in the theater is an important factor to be considered in theater design as well as the installation of sound picture equipment.

Figures 19 through 24 show the correct position or direction for speaker mounting. Figures 19 and 20 show the correct placing of a single speaker installation. If two speakers are used on a horizontal plane, they are placed as shown in Figs. 21 and 22. If these speakers are placed one above the other, they are placed as shown in Figs. 23 and 24. In theaters having a

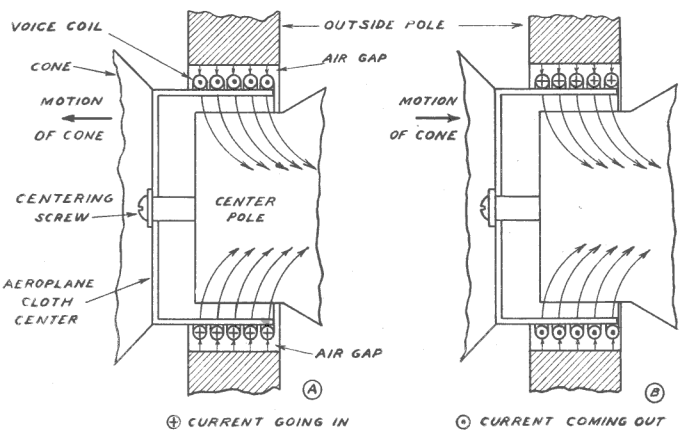


FIG. 18

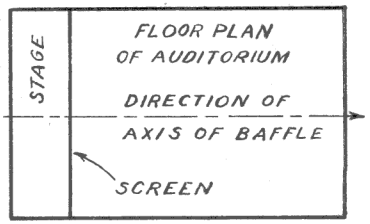
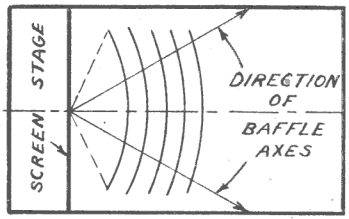


FIG. 19



FLOOR PLAN OF AUDITORIUM

FIG. 21

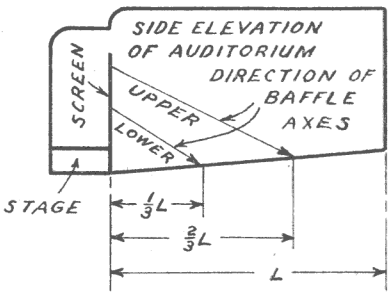


FIG. 23

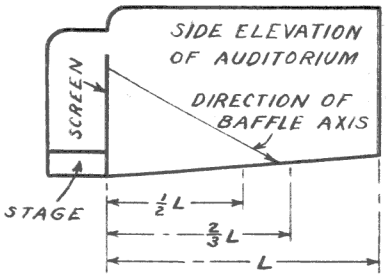


FIG. 20

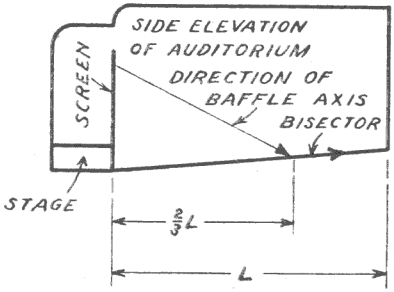


FIG. 22

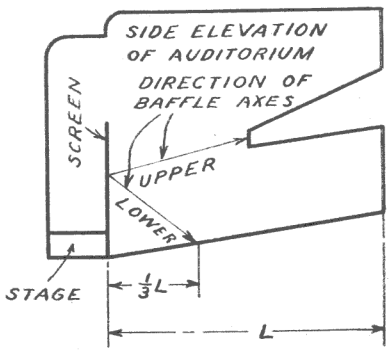


FIG. 24

single balcony, the speakers are directed as shown in Fig. 24, and where two balconies are used, two are directed toward one side of the auditorium and two toward the opposite side.

The walls of the theater, especially in the older theaters, were not designed for sound. Consequently, sound is reflected from these walls as well as the ceiling. In some cases, this reflected sound causes a disagreeable distortion. To prevent this, the walls of the theaters are treated with special sound absorbing material. This reduces the reflected sound from the walls and eliminates all disagreeable distortion.

SCREENS

When sound motion pictures were first introduced, no satisfactory screens for the purpose were available. A high grade screen had been perfected with high reflecting

properties. However, very little sound could penetrate these screens. It was only a short time until these difficulties were overcome. There are two major requirements of a good sound screen. It must have a high ratio of light reflection but must also be porous enough to transmit a high percentage of sound from the speakers in the rear of the screen.

Several different types of screens have been developed, but only two have met with success. One of these is a light weight cloth screen woven fairly loosely to obtain a high sound transmission ratio. The reflecting side of the screen is treated with a silver-like coating. The other type, which has met with good success is a composition material and is completely filled with tiny holes. These transmit the sound but are so small they do not affect the reflecting properties of the screen.

These questions are designed to test your knowledge of this lesson. Read them over first to see if you can answer them. If you feel confident that you can, then write out your answers, numbering them to correspond to the questions. If you are not confident that you can answer the questions, re-study the lesson one or more times before writing out your answers. Be sure to answer every question, for if you fail to answer a question, it will reduce your grade on this lesson. When all questions have been answered, mail them to us for grading.

QUESTIONS

No. 1. Name the two types of sound recording on film?

No. 2. Give two methods of exposing the film strip to light for a variable density film recording.

No. 3. What are two disadvantages of the disc record method of recording in motion picture work?

No. 4. What device translates the light intensity variation from the film into equivalent signal currents for reproduction?

No. 5. Why is it necessary to have two complete film and sound projectors in a theater?

No. 6. What provisions are made to insure that the two projectors and sound recorders cannot operate simultaneously?

No. 7. Is the sound track scanned for reproduction at the same place where the film picture is projected on the screen?

No. 8. What is the purpose of a monitor speaker in the projection room?

No. 9. What method is employed to equalize the voltage output of photo electric cells in a dual projector system?

No. 10. If the film response to AF is insufficient for high fidelity as in Fig. 14A, what may be done to correct this?